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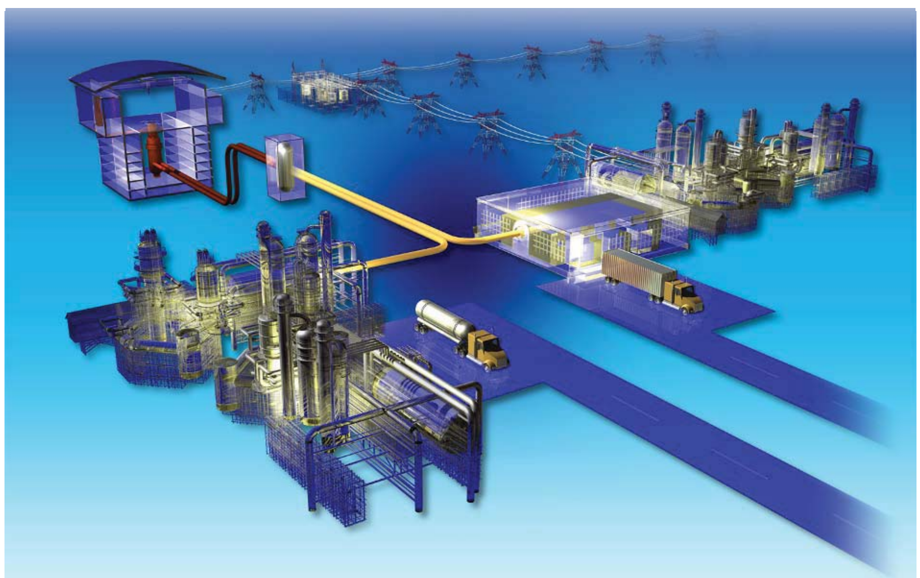
Technical Evaluation Study

Project No. 27147

NGNP Hot Gas Pipe Connector Study



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1. INTRODUCTION

1.1 Description of the Proposed Issue or System

Testing will be required4 to develop the technologies needed for the Next Generation Nuclear Plant (NGNP) Project and move the components, subsystems, and systems from their current technology readiness levels to the levels needed to deploy the NGNP reactor and related systems. The types of tests range from determining the material properties of exotic alloys to transient testing of complete systems to simulate off-normal operations. This work will require a wide variety of research and test equipment and a specialized test facility(ies). Since no specific test facility has been identified, this report refers to a generic Component Test Capability (CTC), which could be provided by test facilities distributed across the country at various vendor's shops, foreign test facilities, or a new Department of Energy test facility.

This effort provides for a conceptual design study and reviews the designs proposed by AREVA and Westinghouse Electric Corporation (WEC) relative to component connection technologies of hot gas pipes (HGPs) to proposed test loops. Finalization of this study will occur during the design development process, once the CTC alternative has been selected.

This study is draft information only to support the August 4th & 5th Component Test Capability decision analysis meeting and will be finalized at a later date based on the alternative selected for the CTC.

This study establishes feasibility criteria for the component test section and the requirements and interface specifications for the CTC test loop hot pipe connection, evaluates alternative designs for these repeated make/break connections (reusable and replaceable), and discusses the approximate spacing needed between these connections. This study:

- Evaluates alternatives for connection to hot duct: flanged, welded, other…
- Describes options for the test section, which considers the questions: Would the test vessel that WEC describes serve as a standardized connection? Are there other configurations that would not be amenable to this standardized connection? What would they need, in terms of floor space, connections, and additional support?
- Discusses accommodating thermal expansion in these hot legs, which considers the question: What kinds of thermal growths and deflections will we encounter?

1.2 Problem Statement

HGPs serve as the major interfaces in the test loop design of the CTC. These pipes allow for the routing of very hot helium gas between major components of the test loops. Because of the high temperatures and pressures (≥950°C, 9 MPa, respectively) of the helium that passes through them, a typical design includes a tube within a pipe concept. In this design, the inner tube, commonly referred to as the inner liner, is fabricated from high temperature material. Insulation is then placed between it and the outer pipe, which can be fabricated from standard piping materials because of the lower temperatures afforded by the intermediate insulation layer. The outer pipe serves as the pressure boundary. The HGPs in the CTC test loops are expected to be 24-inches and larger.

These HGP designs have technical challenges because of their large size and the differences in materials across their sections with the differing coefficients of thermal expansion of their materials. By design, there are large temperature differences between the inner liner and the outer pipe, resulting in large differences in their thermal expansion. Connection of the inner liner and the outer pipe with other loop components is also technically challenging. This is especially true for connections that must be made and broken repeatedly as loop tests change. This study investigates current options for connecting the HGPs, identifies issues, and provides recommendations. The actual design of the HGPs is outside the scope of this study.

1.3 Definitions/Glossary

Defined within the document.

1.4 Acronyms

ASME	American Society of Mechanical Engineers
CTC	Component Test Capability
EH	electric heater
HGD	hot gas duct
HGP	hot gas pipe
HTR-10	High Temperature Reactor (Chinese)
I.D.	inside diameter
NGNP	Next Generation Nuclear Plant
NPS	nominal pipe size
O.D.	outside diameter
PCD	Preconceptual design
QL	Quality Level

WC water cooler

WEC Westinghouse Electric Company

2. BACKGROUND

2.1 Facility, Structure, System, Component Functions

2.1.1 Facility Description

The Department of Energy is responsible for the Next Generation Nuclear Plant (NGNP) Project, which will develop and demonstrate a first-of-a kind very-high-temperature gas-cooled nuclear system with the capability to generate electrical power and also demonstrate nuclear hydrogen production. The future Component Test Capability (CTC) facilities will provide technology development platforms in support of the NGNP Project and the development of high temperature gas thermal-fluidic technologies as applied in heat transfer and transport systems in high temperature gas-cooled reactors. In order for these developmental technologies to be integrated into the NGNP, it will be required that full scale, representative size component tests be conducted on certain items or assemblies. These tests need to be done at NGNP representative conditions, with regards to temperature, pressure, and flow.

The vendors—AREVA and Westinghouse Electric Company (WEC)—have generated preconceptual designs of test loops to provide high temperature, pressure and flow conditions defined in the NGNP Technology Development Roadmaps and associated test plans.[1,2] These test loop preconceptual designs consist of a number of alternative loops and configurations. The test loops relate to this study in that the primary test loop systems are required to supply high temperature helium with hot gas pipes (HGPs). The main emphasis of this study is the connections of the HGPs to the test items and loops.

The AREVA test loops preconceptual design configuration consists of two independent high temperature helium loops that provide the required test conditions established for development and testing of the NGNP components. The AREVA test loops preconceptual design consists of:

- Small Loop—1 MW_t Test Loop—Pipe outside diameter (O.D.) of DN 500 (nominal pipe size [NPS] 20-inch)
- Large Loop—30 MW_t Test Loop:
  - Section Electric Heater (EH) EH1–EH2, pipe O.D. of 457.2 mm (NPS 18-inch)

- Sections EHW–IHX, IHX–steam generator, double hot duct–water cooler (WC) WC2 with pipe O.D. of 711.2 mm (NPS 28-inch)

The WEC test loops preconceptual design configuration consists of five independent or partially interrelated equipment configurations for fulfillment of the overall CTC functions and requirements. The WEC test loops pre-conceptual design consists of:

- Small-scale development tests—No HGP
- Technology development loop—PI 2A_1.2, 1.3, 2.2, and 2.3, pipe O.D. of 610 mm (NPS 24-inch, Sch 80)
- Component Qualification Loop 1—pipe O.D. of 610 mm (NPS 24-inch Sch 80)
- Component Qualification Loop 2—Typical German or Japanese design will be used (up to NPS 42-inch)
- Circulator Test Loop—No high temperature loops.

The WEC designs are fully documented in the *NGNP CTF Test Loop Pre-Conceptual Design Report*.

The various test loop preconceptual designs presented by AREVA and WEC are comprised of the various piping, heaters, circulators, valves, heat exchangers, recuperators, and instruments required for data collection and test loop control. This present HGP connection study is performed in the context of the test loop preconceptual designs presented by AREVA and WEC. Supplemental information from former designs utilized in other facilities and test loops will also be discussed, to the extent that related information is available.

2.1.2 Facility, Structure, System, Component Classification

CTC test loops will be Quality Level (QL) QL-2. This study will be used as a supporting document in a future procurement and is QL-3.

The CTC facilities are anticipated to be high hazard, nonradiological facilities.

The CTC facility designs will employ safety concepts utilizing defense-in-depth provisions to protect plant systems, structures and components, and the health and safety of operating personnel. Safety concepts will rely on robust designs and high quality equipment specifications that provide high design margins. Test loop components will be designed to the applicable national codes and design standards provided by such organizations as the American Society of Mechanical Engineers (ASME)/American National Standards Institute, Institute of Electrical and Electronics Engineers, National Electrical Code, National Fire Protection Association, and Tank Equipment Manufacturers Association.

The CTC facilities will provide the capability to test reactor and ancillary components to demonstrate licensability of components and associated operations. These tests can be demonstrated without requiring the CTC facility to be licensed by the Nuclear Regulatory Commission.

Preliminary safety analysis, hazards analysis, and quality assessment is provided for the AREVA and WEC test loops preconceptual designs in their referenced reports.

2.2 Historical Overview

This section provides some historical perspective on examples of HGPs, referred to in this section as hot gas duct (HGD), that have been used in actual high temperature loop configurations. Where possible, attention is given to the method of connecting the pipe into the system.

2.2.1 HTR-10[3]

The Chinese modular High Temperature Reactor (HTR module) concept developed by Siemens/Interatom in 1981 was the first small, modular-type reactor concept to be proposed worldwide; the thermal output of the pebble bed HTR-10 module is 200 MW.[4,5] The HGD is a unique component exclusively found in this type of reactor where the nuclear core and the power conversion unit are each placed into separate pressure vessels, which need a connecting duct. Passing through the HTR-module core, hot helium gas is conveyed via the liner tube of the horizontal HGD to the steam generator. After being cooled down, the cold helium gas is returned to the lower section of the reactor pressure vessel via a passage between the coaxial inner tube and the outside pressure pipe of the HGD. Figure 1 shows the position of the HGD in the reactor system.

Figure 1 is somewhat deceiving in that it does not show the building structure that surrounds the reactor or the steam generator. In this case, the HGD penetrates through a wall. implying that the HGD was first connected to either the reactor vessel or the steam generator vessel and then to the other, rather than put in place after the two main vessels were installed. That is, the HGD was not meant to be removed without removal of either the reactor vessel or the steam generator. The outside diameter of the HTR-10 HGD was 570 mm (NPS 22 inch) and it provides a slip flanged connection to the reactor and the steam generator vessels.

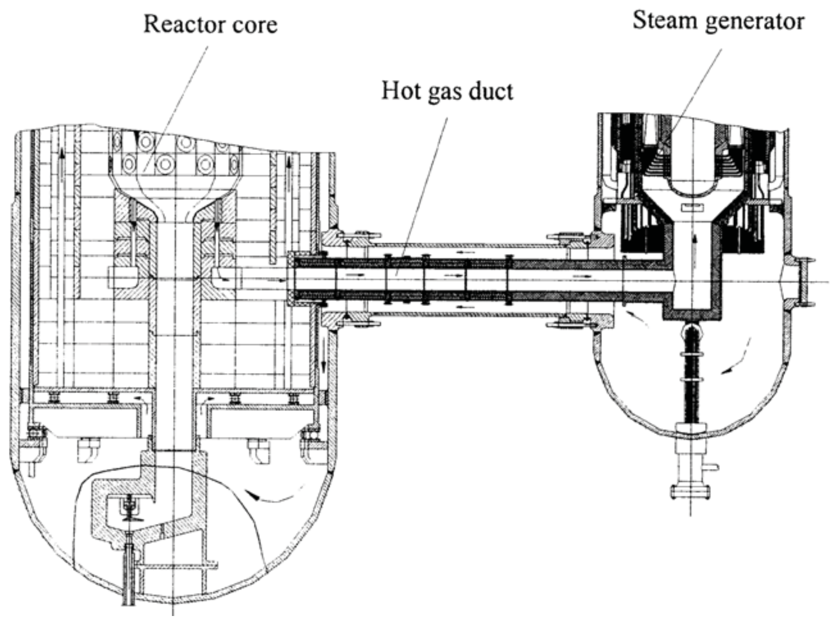


Figure 1. Position of HGD in HTR-10 system.

The structure of the HTR-10 HGD is shown in Figure 2. One end connects to the reactor pressure vessel by a flange, and the other end connects to the steam generator vessel by a flange. The duct has the following functions:

1. Transporting the hot helium gas from the core to the steam generator
2. Transporting the cold helium gas from the steam generator to the core
3. Providing thermal compensations and avoiding large thermal stresses in various operating conditions.

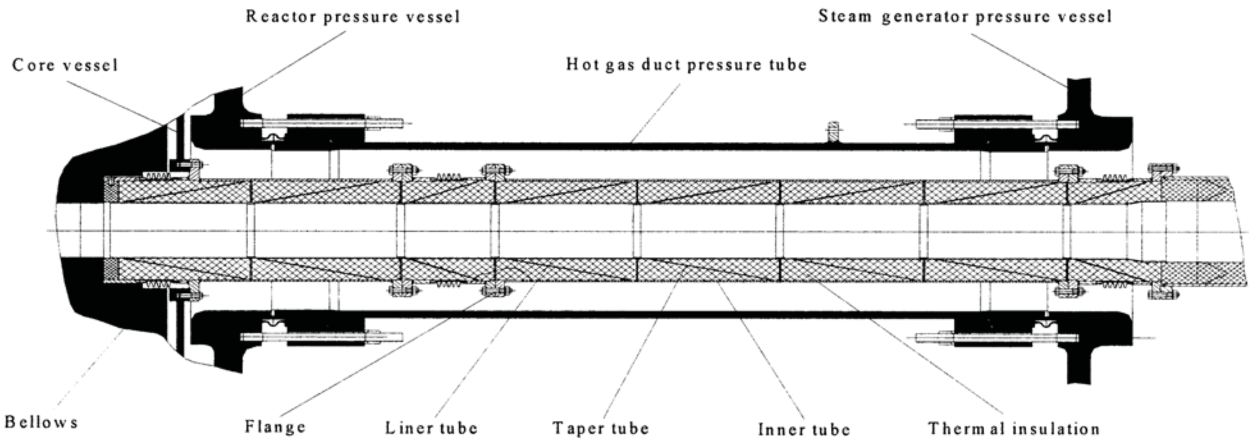


Figure 2. Structure of the HTR-10 HGD.

2.2.2 German KVK Test Loop[6]

In the German Prototype Nuclear Plant nuclear process heat system, the heat generated in the helium cooled core is transferred to the steam reformer and to the subsequent steam generator or intermediate heat exchanger by the primary helium via suitable HGDs. Figure 3 shows a schematic of the process flows that takes place in the system. In both the primary and secondary loop, the HGDs are internally insulated by a ceramic fiber insulation to protect the support tube and the pressure housing from the high helium temperatures as shown in Figure 4. A graphite hot gas liner was used for the coaxial primary duct with an annular gap between the support tube and pressure shell for the cold gas counter flow as shown in Figure 4.

Figure 4 shows the structure of the HGD that was used in the EVA II/ADAM II system at the KVK facility. The duct is shown as fixed flanged on both ends. However, as with the HTR-10 system, the HGD appears to be installed after one major component is installed and then the next component is put into place and connected to it. Again it appears that the HGD was not meant for removal without some major system disassembly. The HGD used in this facility had a diameter of 1,130 mm (NPS 42 inch).

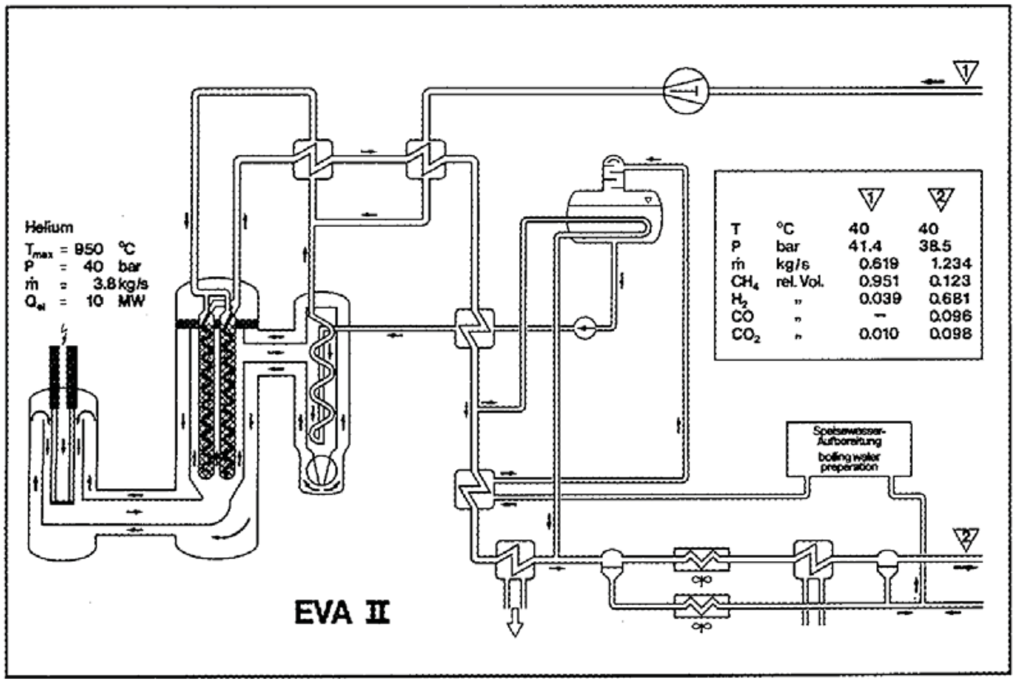


Figure 3. Schematic of the EVA II/ADAM II system.

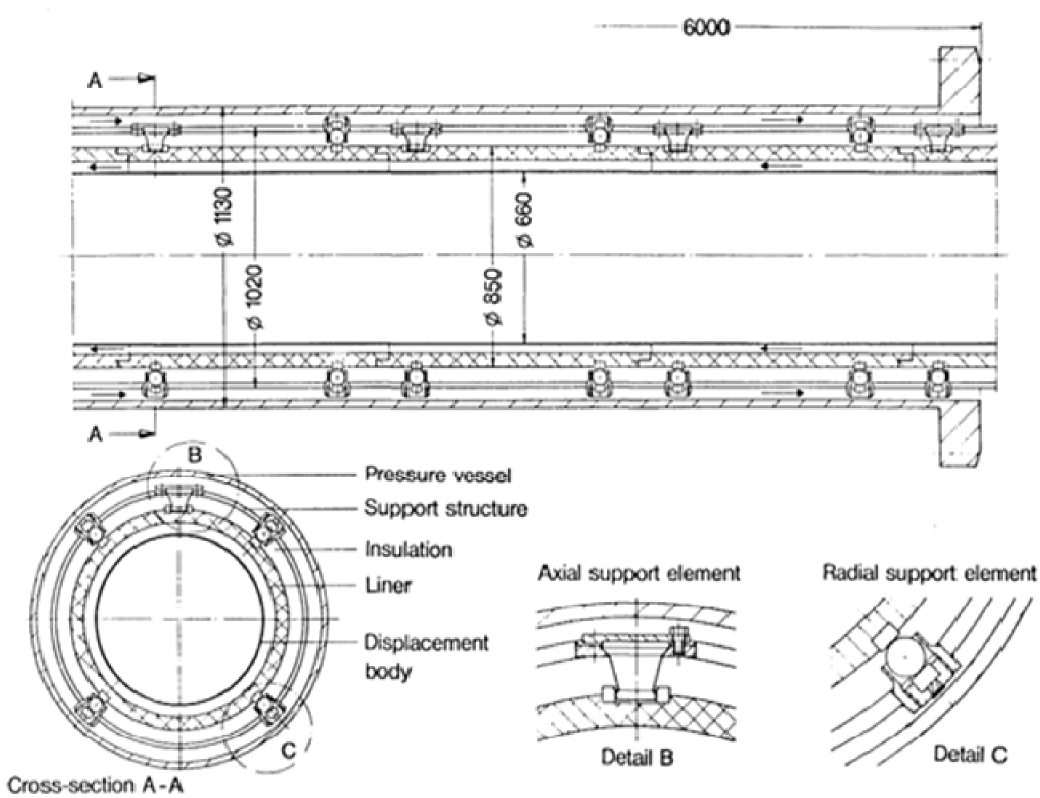


Figure 4. HGD layout for KVK facility.

2.2.3 Helite Loop at Commissariat à l'Energie Atomique[7]

Information about the Helite loop design was not readily available. Therefore, connection technology of the HGPs in the system is yet to be determined. However, a schematic showing the HGPs in the Helite loop (European Raphael Project[8]) is presented in Figure 5.

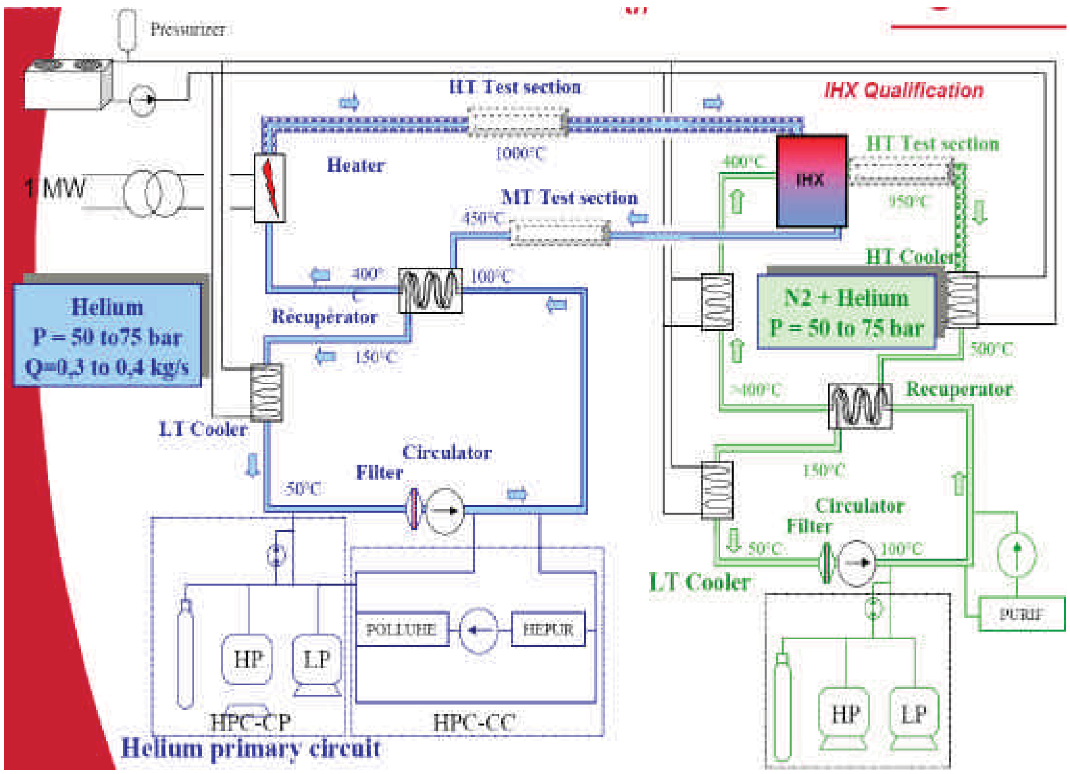


Figure 5. Schematic of Helite loop.

2.3 AREVA and Westinghouse (WEC)

The AREVA and WEC proposal provide preconceptual designs for the HGPs. They also provide some detail as to the design of the overall elements. AREVA's concept provides the most detail regarding the different types of HGPs that would be employed in their system. Figures 6 and 7 show concepts of the different pipe configurations that they propose. Only one, however, shows the method for connection to another entity. That is the branch pipe element showing a weld neck flange and a blind bolted to it.

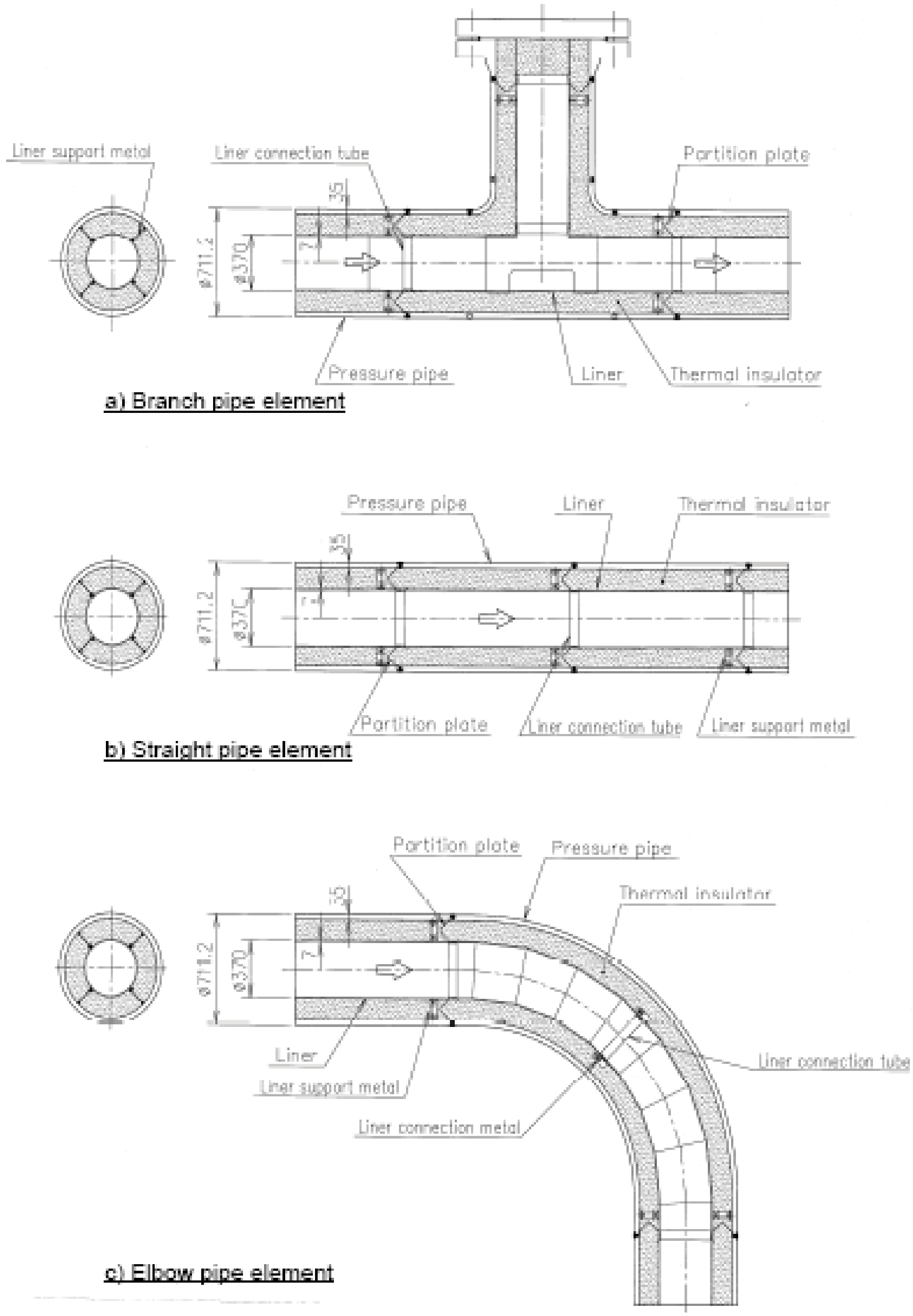


Figure 6. HGP elements in AREVA PCD lines EH2-IHX, double hot duct, test equipment WC2, IHX–steam generator.

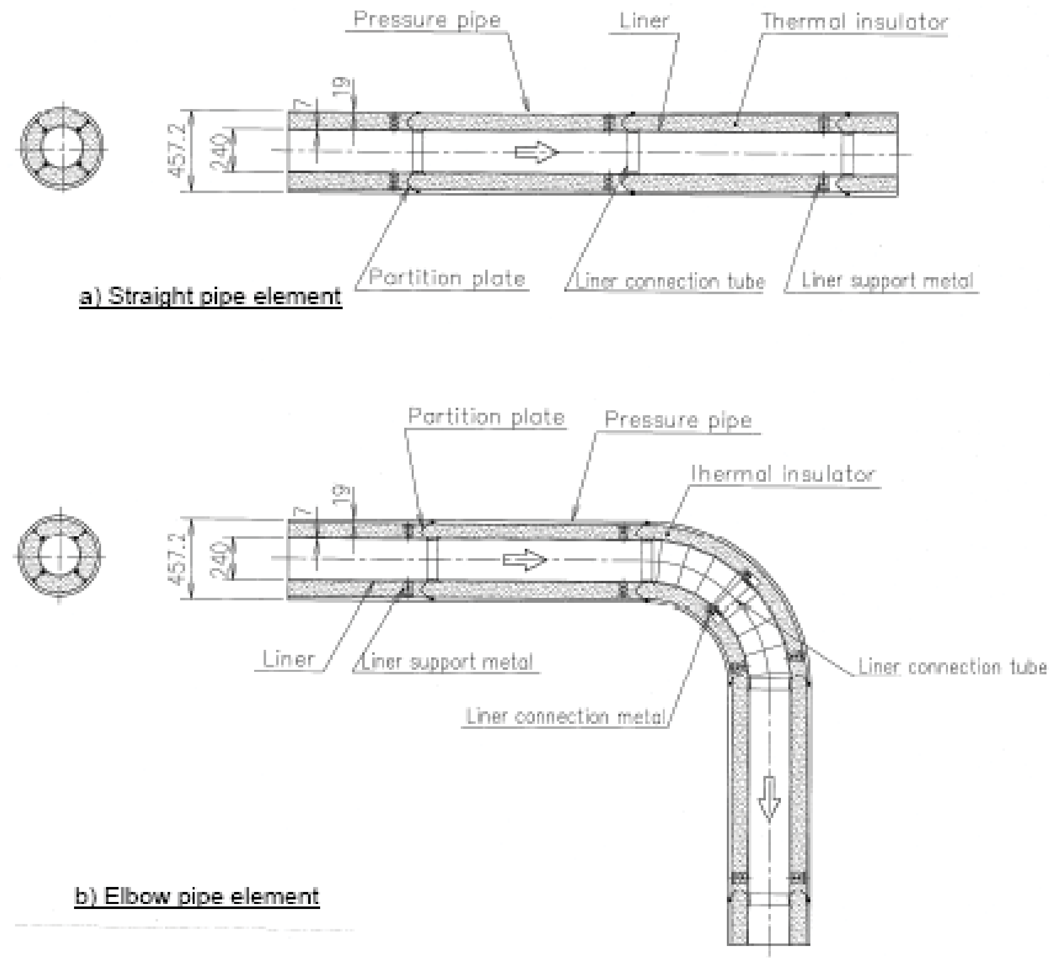


Figure 7. AREVA PCD concept of HGPs used in line EH1 and EH2.

The WEC proposal identifies the HGPs in similar design to the AREVA concept. They present and describe a preconceptual view of the cross section of a typical HGP and also show the cross-section of a partial joint (see Figure 8). The concept shows the use of weld neck flanges and a gasket for making connections. As with the AREVA concept, details on the actual connection, configuration, or sealing medium are not provided.

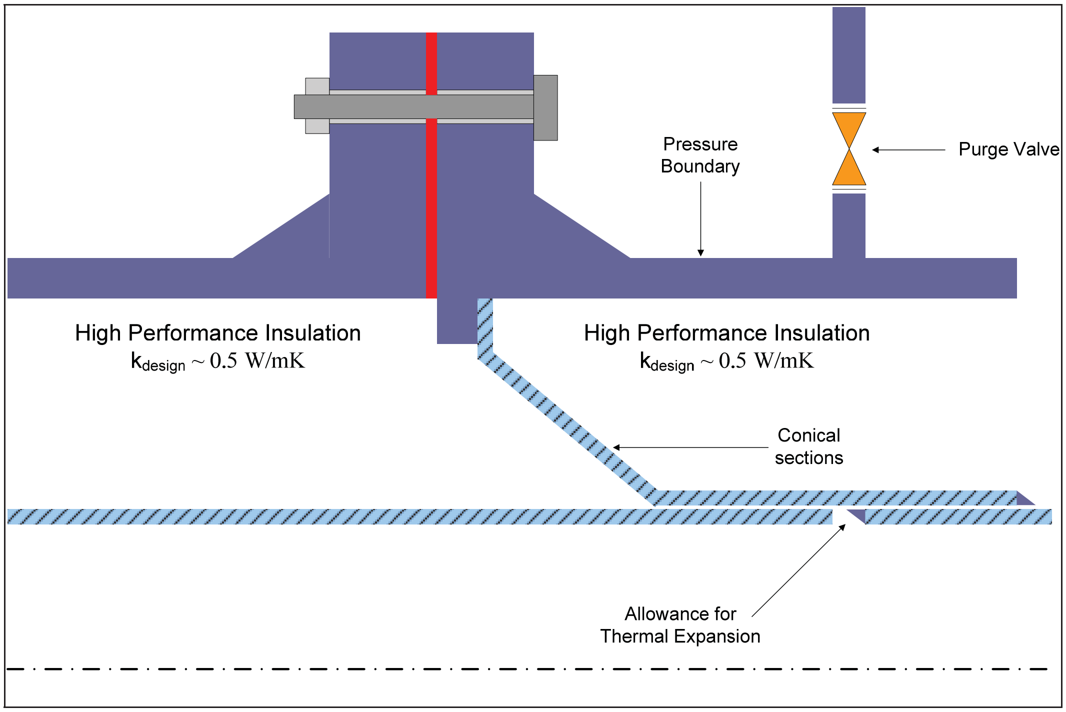


Figure 8. WEC preconceptual version of a partial HGP cross section showing a flanged connection.

3. PROPOSED SOLUTION(s)

This section provides information on alternatives for connection of the HGPs to test articles and test loops in the proposed facility, the purpose of the alternative selection, and a short evaluation. While the primary purpose of any pipe joint is to withstand internal pressures, it is also important to remember the considerable stresses that occur at the joint due to the effects of thermal expansion and contraction, line loads, supports, and other factors. Also, poorly designed and rigid piping systems, the overloading of bolts or uneven bolt tensioning, faulty machine work, misalignment of flange faces, and similar conditions will also impose additional stresses at the joint. Historically, failure to consider such stresses has been the cause of many joint failures, some with catastrophic results. With this application at high temperatures and pressures and using a gas as the pressurizing medium, it is extremely important to perform in-depth design followed by sensible, well planned experimentation and testing to ensure plant safety and longevity.

Because the HGPs will be a "tube inside a pipe" configuration, differential thermal expansion issues will arise between the inner tube and outer pipe. The inner tube conveys the hot helium between major components. The outer pipe provides the pressure boundary for the assembly. The annular area between the inner tube and outer pipe is filled with insulation and engineered fixtures for centering the one within the other and, in some cases, conveying the cooler helium returning to the loop heat source for reheat. Historically, thermal expansion issues, in similar equipment, have been handled using slip joints and bellows assemblies for the center tubes and bellows and other compliant means for the outer pipe. This is a subject that will require considerable research and investigation during conceptual design of the CTC loops.

A study on joint connections may be divided into two general categories. The first is the method of connection of the joint to the pipe. The second is the type of facing on the connection and the method for sealing of the joint. These will be investigated in subsequent sections of this study.

3.1 Elements/Functions of Proposed Solution(s)

This section describes each of the potential technologies and how they function.

The major commercial options for connection of the HGPs to the system are: ASME B16.47/B16.5 flanges—specialized flanges (using metal-to-metal sealing technologies) and welded. These options are described in greater detail in the following subsections.

3.1.1 Flanged (ASME B16.47/B16.5)[8,9]

These types of flanged connections represent the most standard type of piping connections currently available and are used in virtually all facets of pneumatic and hydraulic systems. ASME B16.47 represents flange sizes larger than 24-inches NPS while ASME B16.5 represents flange sizes 24-inches NPS and smaller.

Typical styles of ASME flanges are:

1. *Screwed flanged joints*. These do not apply for use at the required system temperatures and pressure, therefore they are not presented in further detail.

2. *Slip-on flanged joints*. These are designed to slide onto the pipe and are then welded to the pipe. The flange is welded either on the back or the back and front of the flange to pipe interface. Both methods require accurate alignment of bolt holes prior to welding. Because of distortion, refacing of the flange is recommended subsequent to welding. Based upon the amount of care and effort required to make this joint first class increases its cost to a point where other options may be desirable (see Figure 9).

Figure 9. Typical slip-on flange.

3. *Welding neck flanged joints*. These joints are widely applicable. They are available in all the working pressures and various facings, with inside diameter (I.D.) and O.D. of standard and extra strong pipe as well as the various schedule number thicknesses. They can also be bored to any special I.D. required. This flange also requires accurate alignment of bolt holes prior to welding. Distortion of the flange face is limited due to the weld area being sufficiently removed (by distance) from the face (see Figure 10).

Figure 10. Typical weld neck flange.

4. *Lap flanged joint*. This type of joint avoids the necessity of accurate alignment of bolt holes in that the flange is free to

revolve on the pipe. This permits it to be readily aligned with bolt holes of a mating flange. An added advantage of this type is the option of using an ordinary steel flange behind the lap on alloy pipe without sacrificing internal corrosion protection (see Figure 11).

Figure 11. Typical lap joint flange.

5. *Socket weld flanged joint*. These do not apply for use at the size required (they are only used up to 3-inches) and are therefore not presented in further detail.

ASME flanges are arranged by class. The classes are listed as primarily 150, 300, 400, 600, 900, 1,500, and 2,500 pounds. This class number represents the pressure-temperature ratings as established by ASME standards. The standard classifies the required pressure-temperature rating based upon flange material grouping. For the pressure-temperature expected for the pressure boundary of the HGP (350ºC, 9.0 MPa) the rating class for the flanges would be selected as either 600 or 900, depending on the flange material selected. In accordance with current standards,[8,9] a temperature consideration is applied based upon the process temperature. Temperatures greater than 400ºC are considered high temperature applications for flanges above Class 150, meaning that this application is considered to be a low temperature application of the flanges. The standards also provide direction as to the type and size of bolting to be implemented with these flanges.

Another key feature of standard flanges is the facing. Based upon current ASME standards, the types of facings are equal in pressure-temperature ratings, with the qualification that the user is responsible for selecting gaskets of suitable dimension and material. The types of facing for steel (or alloy) flanges are: raised face, small tongue and groove, large tongue and groove, small male and female, large male and female, and ring joint. Machining and installation difficulties are enhanced with all but the raised face type. However, special attention to machining tolerances, degree of finish, and careful assembly make these desirable joints for extreme service conditions when the additional costs can be justified. This is especially true of the ring joint.

3.1.2 Metal-to-Metal Seals and Connectors

A variety of connectors have been invented for use in high pressure and temperature situations. These commonly employ the use of specialized metal flanges, seals, and closure clamping systems. Two examples of this style of connector is the Aeroquip "Conoseal" connector, and the Grayloc connector, manufactured and distributed by Eaton Aerospace and Oceaneering, respectively. These connectors found significant use in pressurized and boiling water reactor facilities and are in use around the world today. In this application, these connectors will be sealing against helium at 350ºC and 9.0 MPa temperature and pressure, respectively. As such, additional research and engineering will be required regarding the appropriate flange and seal materials to be used in the CTC loop studies.

Both companies were contacted for information regarding their connectors. Appendices B and C provide information regarding their application, design, and other needed information. Information on these types of connectors is provided to familiarize the reader with the technology. Figures 12 and 13 provide a pictorial view of the Grayloc connection, explain how the seal works, and compare it (in size) with a standard flanged connection.

Figure 12. Example of Grayloc clamp connector assembly.

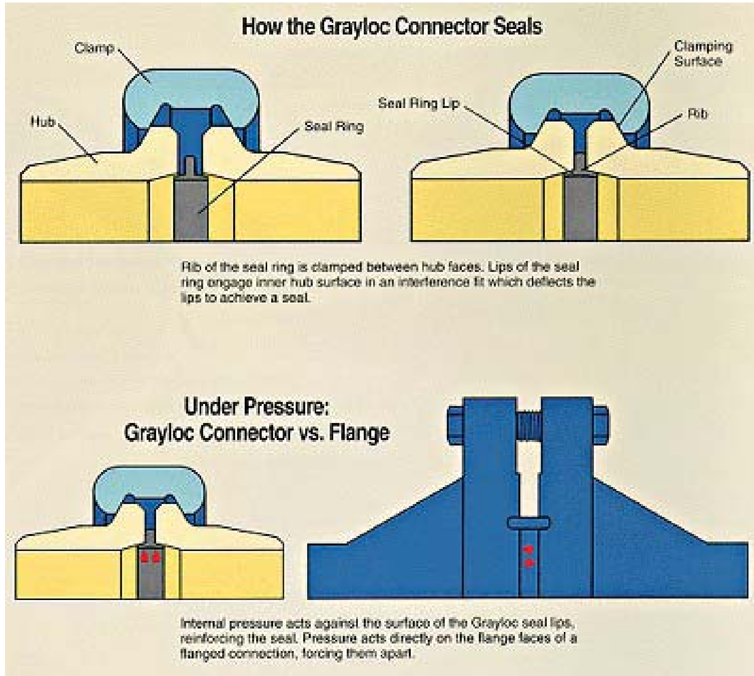
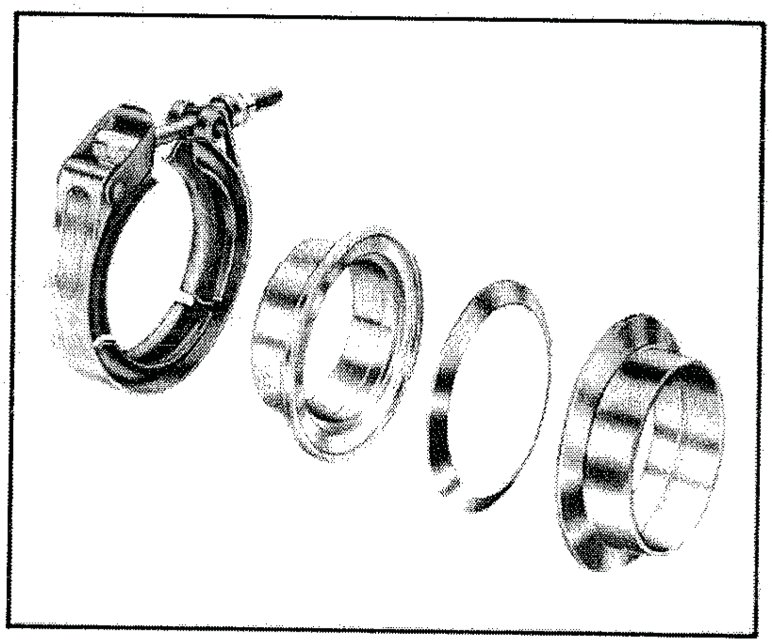


Figure 13. A representation of the Grayloc connector and how it works.

The Conoseal connector although similar employs a different type of hub, seal ring, and clamp assembly. Figure 14 provides a representation of the flange and seal assembly.



Medium weight Conoseal joint with T-Bolt quick coupler.

Figure 14. Exploded view of Conoseal connection hardware.

Both types are used for high temperature and pressure applications with liquids and gases, but application sizes vary between them. The Grayloc clamp system is typically limited to NPS 24-inch or less. Grayloc, however, designs and manufactures alternative connections for use in larger pipe sizes. They call this the Grayloc Compact Flange. It appears to be similar in design to ASME flanges, but is 70% of the width and 36% of the height of standard flanges. It also uses the patented Grayloc metal seal ring. Grayloc publishes that they have built this system up to a pipe size of 144 inches in diameter (see Figure 15). Appendix C provides additional information on the compact flange.

The Conoseal connection has been used in sizes that exceed 80 inches in diameter. Additional information regarding the Conoseal connection can be found in Appendix B of this document. At this writing, pressure-temperature information for these large size Conoseals is forthcoming from the vendor. All three connection systems are available in a wide range of materials, to meet system requirements.

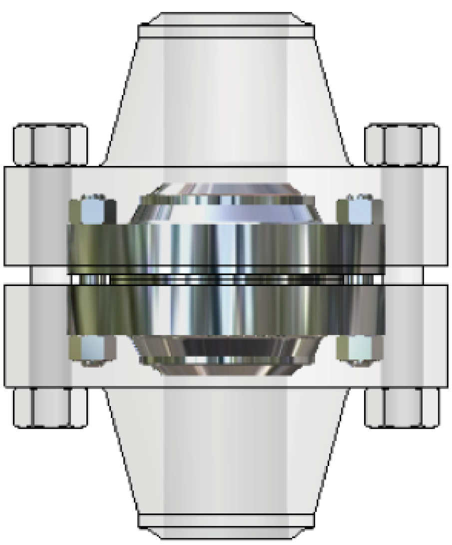


Figure 15. The Grayloc compact flange assembly superimposed on top of a standard ASME flange, showing size difference for same class of connection assembly.

3.1.3 Welded

Properly welded pipe connections provide the best option for leak prevention of the high pressure-temperature helium gas from the system. The major drawback with welding is the permanent nature of the installation. The test loops of this facility will be adjusted and modified a significant number times in order to perform the number of tests that have (and will be) identified to qualify equipment.

The process of welding may be performed using a variety of weld joints to accommodate the needs of the facility. Butt welding and welding both ends of a pressure sleeve over two sections of pipe are the primary candidates for this application.

3.2 Evaluation of Alternatives

This section provides an evaluation of advantages and disadvantages of each proposed technology.

3.2.1 Advantages

- *ASME flanges*. These flanges are commercially and commonly available. They come in a wide variety of materials and sizes for most pressure-temperature applications. They provide a number of sealing surface types that provide graded levels of sealing capability, dependant on the leak tightness required. Dependant on the style selected for use, they can provide relatively easy assembly (as with the lap joint type). These are potentially the least expensive of the flanged options and would require the least amount of time for procurement. Based upon contact with Texas Flange, even large code qualified flanges up to 200-inches in diameter and class 900 are available in 12 weeks or less after receipt of order. Confirmation of this should be by vendor quotation during conceptual design.

- *Metal-to-metal connections*. These assemblies are similar to flanged connections in their application. The clamp-type differs in the closure mechanism applied. These use a clamp-type mechanism that pulls the two machined flanges together against a metal seal ring. Therefore, they don’t require the lining up of bolt holes to create the seal. Grayloc publishes that their seal ring is self-aligning. Installation of the clamp is purportedly less difficult than installation and subsequent tension of flange bolts.

  The Grayloc Compact Flange is similar in design to the ASME flanges only substantially smaller and more compact for the same pipe diameter and pressure-temperature class. It employs a self-aligning metal seal ring (see Appendix C).

- *Welded*. Welded joints provide the best assurance against leakage and are the best option to support the piping system with minimized support loads because they don't have the additional weight of flanges, bolts, clamps, and sealing materials. The welded joint would take much less floor space than either of the flanged connection options. Misalignment of the piping can be more easily accommodated in the welded design by grinding the ends of the pipes to match rather than straining the piping system. This lends itself to alignment fixturing for welding of pipe, which is commonly used and understood. If a cutting machine (such as TRI-TOOL technology) is used to cut out welds, it simultaneously machines the new weld preparations on the pipe end.

Welding a coupling sleeve over the two ends of pipe may prove to be an acceptable method for connecting the pipe ends. Flange faces would not be required to match. The sleeve and the other pipe supports would maintain the alignment during assembly. With the transport of helium gas, contamination of the interstitial space between the outer pipe and inner sleeve surfaces is not a concern. The welding of the sleeve is done with simple fillet welds that are easily machined off when changes are necessary. As with the other connection technologies, this alternative requires further study.

3.2.2 Disadvantages

- *ASME flanges*. At the sizes being discussed and for the pressure-temperatures required, the flanges are very large and bulky. A single NPS 24-inch 900 pound class weld neck flange has dimensions of 41-inches wide by 11.75-inches thick and weights 2,107 pounds. Alignment of two flanges in a scenario where the connections are repeatedly made and broken poses a technical design challenge for alignment and support of the components. Even the lap joint flange (for the same pipe size) is 41-inches wide by 10.5-inches thick and weights 1,659 pounds. The bolt number and size for these flanges are 20 at 2.5-inch diameter, respectively. For an NPS 42-inch pipe, the dimensions of a weld neck flange are 61.5-inches wide by 14.88-inches thick and the weight is 3,690 pounds. According to Texas Flange,[10] other types of flanges are not offered in this size pipe.

- Metal-to-metal connections. Used in the aerospace, subsea, and nuclear industry, these connectors require the same precision in alignment and assembly as the ASME flanges or greater. They are specialized products that cost more and take longer to deliver than ASME flanges.

- Welded. Butt welded connections would require grinding or machine cutting of the welds in order to remove the test article from the loop. To reassemble the loop, the ground weld would require remachining of the weld preparation area. Elaborate weld fixturing would be required. The piping would need to be extended with each removal in order to maintain location for the test article. Grindings and machining debris from the butt weld area could adversely affect the insulation and helium flow paths within the HGP, as contaminants inside the otherwise clean area.

  When welding an overlapping sleeve over the HGP end and the test article end, each joint will need to be ground or cut out and then rewelded for each loop change. Fixturing for this welding would also be required in order to maintain pipe alignment.

4. ISSUES

Although developed and used in similar applications in the past, HPG designs of HGPs intended for use in this application represent technical challenges to engineers because of the high pressure-temperature helium gas medium and issues associated with its use. This section provides a list of technical issues, which will evolve as HGP designs progress, that require consideration as the design of HGP connections to other entities progresses.

1. The HGP concept involves an insulated tube within a pressure pipe. Design of the end connections shall not interfere with the performance of the insulation in maintaining the pressure boundary temperature at <350°C. Inherent in this is the appropriate selection of materials that make up the liner, insulation, centering device(s), pressure boundary, and connection technology.

2. Design of the HGP shall provide for proper location of and connection to the flow liner tubes in order to maintain continuity of hot helium flowing through the system.

3. The design of HGP connections needs to consider the compliance required for proper alignment and installation of test sections between two HGP connectors An example might be expandable/compressible metal bellows, although additional research should be conducted to determine their suitability for these process conditions.

4. The effect of misaligned flanges (both standard and metal-to-metal) needs to be addressed further. This could have a significant impact on the alternative(s) selected for connection of these piping runs.

5. Regardless of the connection technology employed, design of structural supports to allow for static, dynamic, and thermal loading of the system is necessary.

Designs will need to be validated by approved analytical techniques and programs.

6. The HGP piping and connections will be very large and heavy. Lifting equipment will be required to move and precisely place these items to and from their installed locations. Lifted components should be designed with appropriately engineered lifting points and hardware for this purpose.

7. Design decisions of the type of connection to be used for a specific application in the system need to be made on a life-cycle basis, considering such factors as capital, maintenance, and repair costs; reliability; and the expected number of times the connection will be re-made over the life of the system.

8. If flanged type connections are selected for use in the system, studies should be conducted to select the appropriate materials for gaskets and/or seals used with the flanges to seal against helium leakage.

9. Because of the large component sizes, accurate tensioning of large bolts, if used, presents an engineering challenge that should be studied.

10. If using welded connections, the materials lost with each grinding process when articles are removed should be considered, also whether to replace the removed material (in a spool piece, etc.) or make up the difference in the test article being attached.

11. Additional studies should be conducted on the differential thermal expansion of the HGPs and the appropriate materials, methods, and processes needed to provide for the expansions of the inner tubes and outer pipes relative to each other.

5. RECOMMENDATION

Based upon research performed in this study, connection of HGP in the system may depend entirely on where the connection is located in the system and the function of the connector. For example, if the HGP connector is installed between the heaters and will remain undisturbed during testing sequences, it may be appropriate to permanently weld the entities together, thus maintaining no leakage at those joints. If the heaters are high maintenance items, the HGP connection may change to compact flanges, for ease of installation and removal.

When attaching to test sections, components, and test loops where the connections are repeatedly made and broken, a metal-to-metal seal and flange technology would provide a nondestructive means of system change. For the sizes of pipe suggested, the Grayloc Compact Flange design provides the most economy of size, space, and weight of the flange-type technologies investigated. It also touts a helium leak rate of 10^{-6} atm-cc/s when installed properly. Any of the connection technologies employed will require compliance designed into the system in order to make proper connections with both the inner flow liner and the outer pressure pipe of the HGPs. Further study of HGP connection philosophy, issues, and challenges should be undertaken during the conceptual design phase of this effort. The challenges and issues described in previous paragraphs are significant.

6. IMPLEMENTATION, SCHEDULE AND COST

This section does not apply to this study.

7. CONCLUSIONS

This study investigated some of the history of HGPs (also referred to as HGDs) and found that the majority of connections used have been flange-type. In addition, vendor searches were conducted to understand the technologies that are commercially available for application to the HGP technology discussed herein. The result of these searches confirmed that commercial technologies exist for use with high pressure-temperature helium gas.

The connection technology used in these applications may vary depending upon the location and purpose of the connection within these engineered systems.

8. REFERENCES

1. Farshid Shahrokhi, et al, Areva NGNP Component Test Facility Test Loop Pre-Conceptual Design, Areva Document No. 12-9097512-001, December 2008.

2. Riaan du Bruyn, et al, Westinghouse Electric Company, NGNP CTF Test Loop Preconceptual Design Report, NGNP-CTF MTECH-TLDR Revision 1, December 2008.

3. Z. Y. Huang,* Z. M. Zhang, M. S. Yao, S. Y. He, "Design and Experiment of Hot Gas Duct for the HTR-10, Institute of Nuclear Energy Technology, Tsinghua University, Beijing 100084, China, *Nuclear Engineering and Design 218 (2002)*, Pages 137–145.

4. G. H. Lohnert, H. Reutler, The Modular HTR—A New Design of High-Temperature Pebble-Bed Reactor, Nuclear Energy 22 (3), 1983, Pg. 197-200.

5. G. H. Lohnert, Technical Design Features and Essential Safety-Related Properties of the HTR-Module, Nuclear Engineering and Design, 121 (2), 1990, Pg. 259-270.

6. H. Stehle, E. Klas, "Status of the Development of Hot Gas Ducts for HTRs," IAEA, *Specialists meeting on Heat Exchanging Components of Gas-Cooled Reactors*, Dusseldorf, 16-19 April 1984.

7. Hittner, D; Bogusch, E.; et al., *RAPHAEL: The European Programme for the Development of Advanced Technologies for High and Very High Temperature Reactors*, Luxemburg, FISA 2006.

8. ASME B16.5-2003, "Pipe Flanges and Flanged Fittings: NPS ½ Through NPS 24 Metric/Inch Standard."

9. ASME B16.47-2006, "Pipe Flanges and Flanged Fittings: NPS 26 Through NPS 60 Metric/Inch Standard."

10. Texas Flange Catalog, www.TEXASFLANGE.COM, PH: 877-610-8924

9. APPENDICES

Vendor information/cited information, etc. is provided here.

Appendix A, Standard ASME 900 LB Flanges

Appendix B, Conoseal Connections

Appendix C, Grayloc Connections

Appendix A—Standard Flange Connector Information

ASME B16.5-2003, "Pipe Flanges and Flanged Fittings: NPS ½ through NPS 24 Metric/Inch Standard," Pages 93–94.

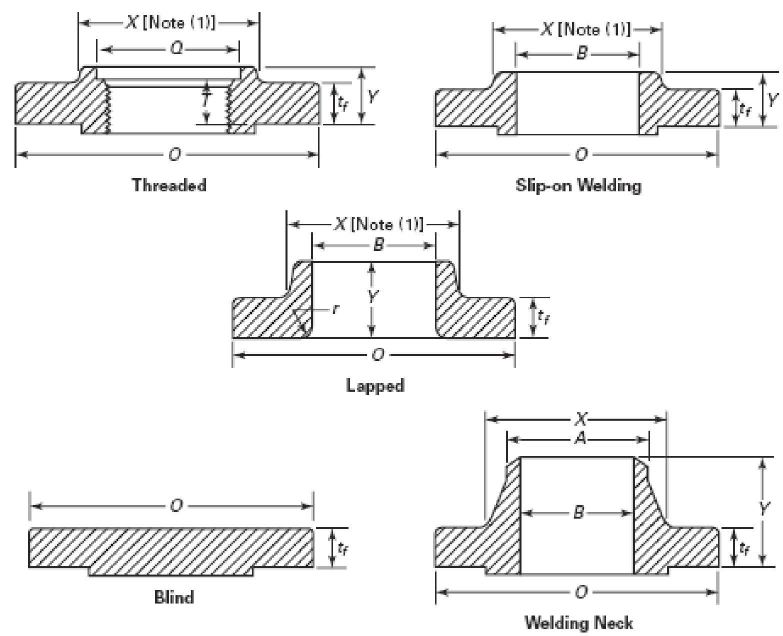


Table 18 Dimensions of Class 900 Flanges

1	2	3	4	5	6	7	8	9	10	11	12	13	14
					Length Through Hub			Thread Length	Bore				
Nominal Pipe Size, NPS	Outside Diameter of Flange, O	Thickness of Flange Min., t_f	Diameter of Hub, X	Hub Diameter Beginning of Chamfer Welding Neck, A [Note (2)]	Threaded/ Slip-on, Y	Lapped, Y	Welding Neck, Y	Threaded Flange Min., T [Note (3)]	Slip-on Min., B	Lapped Min., B	Welding Neck, B	Corner Radius of Bore of Lapped Flange and Pipe, r	Counterbore Threaded Flange Min., Q
½	Use Class 1500 Dimensions in these sizes [Note (4)].												
¾													
1													
1¼													

Table 18 Dimensions of Class 900 Flanges (Cont'd)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
				Hub Diameter Beginning of Chamfer	Length Through Hub			Thread Length Threaded Flange	Bore				
Nominal Pipe Size, NPS	Outside Diameter of Flange, *O*	Thickness of Flange Min., t_f	Diameter of Hub, *X*	Welding Neck, *A* [Note (2)]	Threaded/ Slip-on, *Y*	Lapped, *Y*	Welding Neck, *Y*	Min., *T* [Note (3)]	Slip-on Min., *B*	Lapped Min., *B*	Welding Neck, *B*	Corner Radius of Bore of Lapped Flange and Pipe, *r*	Counterbore Threaded Flange Min., *Q*
1½													
2													
2½	Use Class 1500 Dimensions in these sizes [Note (4)].												
3	240	38.1	127	88.9	54	54	102	42	90.7	91.4	To be specified by Purchaser	10	92.2
4	290	44.5	159	114.3	70	70	114	48	116.1	116.8		11	117.6
5	350	50.8	190	141.3	79	79	127	54	143.8	144.4		11	144.4
6	380	55.6	235	168.3	86	86	140	58	170.7	171.4		13	171.4
8	470	63.5	298	219.1	102	114	162	64	221.5	222.2		13	222.2
10	545	69.9	368	273.0	108	127	184	72	276.2	277.4		13	276.2
12	610	79.4	419	323.8	117	143	200	77	327.0	328.2		13	328.6
14	640	85.8	451	355.6	130	156	213	83	359.2	360.2		13	360.4
16	705	88.9	508	406.4	133	165	216	86	410.5	411.2		13	411.2
18	785	101.6	565	457.0	152	190	229	89	461.8	462.3		13	462.0
20	855	108.0	622	508.0	159	210	248	93	513.1	514.4		13	512.8
24	1,040	139.7	749	610.0	203	267	292	102	616.0	616.0		13	614.4

GENERAL NOTES:

(a) Dimensions of Table 18 are in millimeters. For dimensions in inch units, refer to Annex F, Table F18.

(b) For tolerances, see para. 7.

(c) For facings, see para. 6.4.

(d) For flange bolt holes, see para. 6.5 and Table 17.

(e) For spot facing, see para 6.6.

(f) For reducing threaded and slip-on flanges, see Table 6.

(g) Blind flanges may be made with or without hubs at the manufacturer's option.

(h) For reducing welding neck flanges, see para. 6.8.

NOTES:

(1) This dimension is for large end of hub, which may be straight or tapered. Taper shall not exceed 7 deg on threaded, slip-on, socket-welding, and lapped flanges. This dimension is defined as the diameter at the intersection between the hub taper and the back face of the flange.

(2) For welding end bevel, see para. 6.7.

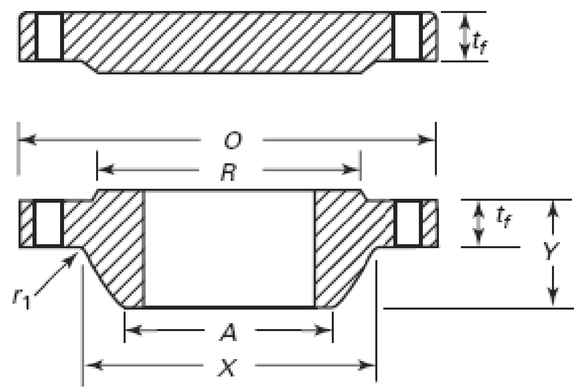
(3) For thread of threaded flanges, see para. 6.9.

(4) Socket welding flanges may be provided in NPS ½ through NPS 2½, using Class 1500 dimensions.

ASME B16.47-2006, Large Diameter Steel Flanges, NPS 26 Through NPS 60 Metric/Inch Standard.

ASME B16.47-2006

Table I-38 Dimensions of Class 900 Series B Flanges



Nominal Pipe Size	O.D. of Flange, O	Minimum Thickness of Flange, t_f [Note (1)] WNF	Minimum Thickness of Flange, t_f [Note (1)] Blind	Length Through Hub, Y	Diam. of Hub, X [Note (2)]	Hub Diam. Top, A [Note (3)]	Raised Face Diam., R	Drilling: Diam. of Bolt Circle	Drilling: No. of Bolt Holes	Drilling: Diam. of Bolt Hole	Diam. of Bolt	Minimum Fillet Radius, r_1
26	40.25	5.31	6.06	10.19	29.25	26.00	30.00	35.50	20	2⅝	2½	0.44
28	43.50	5.81	6.56	10.88	31.38	28.00	32.25	38.25	20	2⅞	2¾	0.50
30	46.50	6.12	6.93	11.38	33.50	30.00	34.50	40.75	20	3⅛	3	0.50
32	48.75	6.31	7.31	11.94	35.75	32.00	36.50	43.00	20	3⅛	3	0.50
34	51.75	6.75	7.68	12.56	37.88	34.00	39.00	45.50	20	3⅜	3¼	0.56
36	53.00	6.81	7.94	12.81	40.00	36.00	40.50	47.25	24	3⅛	3	0.56

Appendix B—Conoseal Connections

The following vendor information represents a "catalog cut" of available information. Reference for acquiring addition information is also included.

Aeroquip

AEROSPACE ENGINEERING BULLETIN

CONOSEAL JOINTS

AEB 197A

CONOSEAL® joints, fittings and Conomate™ couplings

The Aeroquip Conoseal principle provides a circumferential metal-to-metal seal with essentially "zero leakage." Designs shown in this bulletin include the Conomate coupling, light weight and medium weight tube joints, and tube fittings.

Light Weight Conomate Joints

Light weight Conomate joints offer great strength, high reliability and optimum loading characteristics. No-weld construction provides high joint integrity by eliminating the possibility of undiscovered weld stress.

Standard Light Weight and Medium Weight Joints

Standard tube joints, using either a T-bolt, quick coupler latch or a Conomate coupling permit quick, easy assembly and rapid disassembly.

Union Fittings for Small Diameters

These light weight fittings, available in sizes 1" and under, are highly reliable and require no periodic retorquing. They can be supplied with either socket or butt weld flanges.

CONOSEAL joints and union fittings

The Conoseal joint consists of a male and female flange and frusto-conical shaped gasket (or gaskets) which are contained either by bolts, V-Band couplings or a threaded union. These joints employ a sealing principle which was developed to provide industry with an all-metal joint capable of withstanding high pressures and extreme temperatures without leakage.

Conoseal joints can be supplied to withstand temperatures ranging from –450°F. to +2000°F., and pressures up to 20,000 psi. These joints are suitable for critical sealing applications requiring leakage rates within the capability range of a helium mass spectrometer leak detector. They are adaptable for joining systems such as cryogenic lines, lines for high temperature and high pressure gases and fluids, liquid metal systems, ultra high vacuum lines, etc.

Conoseal joints can be used on systems involving dissimilar metals. The joints are reusable by simply replacing the gasket. Components or complete joints can be furnished in a wide range of materials and configurations as outlined on the following pages.

Special configurations can be designed to suit the application and large diameters can also be supplied. Contact Aeroquip or your nearest sales engineer for designs and sizes not shown in this catalog.

FEATURES

- Handles extreme temperatures (–450°F. to +2000°F.)
- Accommodates extremely high pressures
- Withstands severe vibration
- Quick assembly and disassembly
- No periodic retorquing required
- Virtually leakproof (leakage rate is less than 1×10^7 standard cc/second of helium)
- Many sizes and configurations
- Wide range of materials
- Improved elliptical gasket available that retains itself in the flange cavity for ease of installation.

Sealing Principle

Illustration 1: The gasket is shown inserted between the mating flanges prior to assembly of the coupling or bolts. As the flanges are moved axially together, the gasket is loaded radially against the mating flange lips. The inclined flange surfaces are brought to bear against the gasket sides to control buckling.

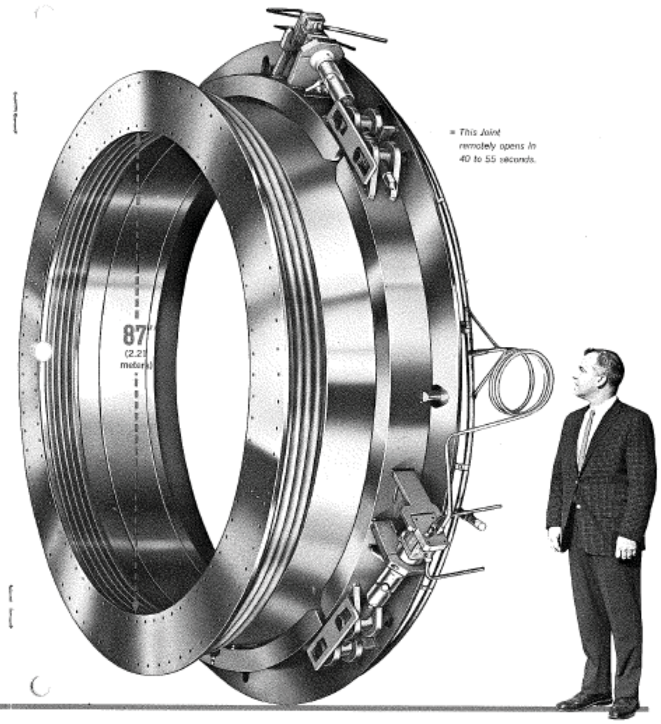
Illustration 2: The gasket is shown completely enclosed. The mechanical advantage of the Conoseal joint design induces a plastic flow condition on the sealing edges of the gasket. This insures 100% metal-to-metal contact.

In effect, the Conoseal joint design embodies the recovery characteristics of an elastomeric joint. Since the gasket cross sectional height is greater than the vertical distance between flange lips, its sealing is not limited to the fully compressed position. Proof testing has indicated flange axial separation capabilities up to .06 inches without leakage.

SIZE IS NO FACTOR IN PRODUCING LEAKPROOF CONOSEAL JOINTS

From this  **...to this**

⅛" Tube Dia.
(3.175 m.m.)



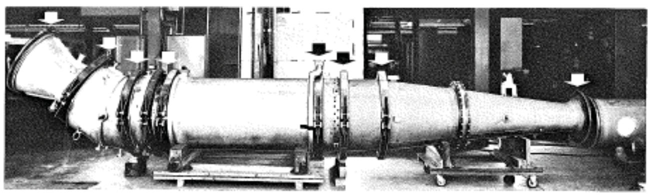
■ This Joint remotely opens in 40 to 55 seconds.

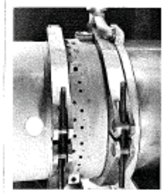
The Double-Seal CONOSEAL Joint on the right is 87" in diameter (2.21 meters). The bolts joining the coupling segments are remotely activated by air-impact motors. The joint is used to connect the nuclear engine exhaust ducting to the engine test stand. It has a leakage rate of 1.2 x 10−8 standard cc/second of helium.

Appendix B

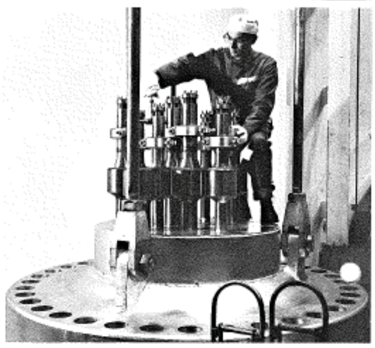
CONOSEAL JOINT APPLICATIONS

■ ISOTOPE SHIPPING CONTAINER incorporates a Conoseal Joint closure, with a leakage rate of 1 x 10⁻⁷ std. cc/sec. helium in 1 & 1½ inch sizes. They withstand temperatures from —450°F to +2000°F. at pressures up to 20,000 psi. They can also be supplied to withstand ultra high vacuum of less than 1 x 10⁻⁸ torrs.

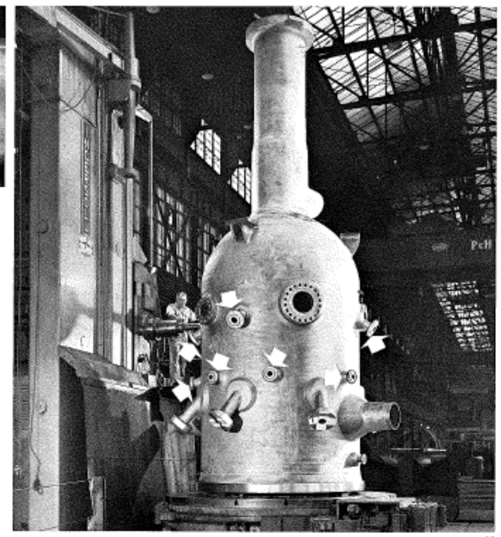




■ EXHAUST DUCTING: Temperatures to 1050°F. (606°C.) and pressures to 650 psig. (49 ATA) Close up of Latch Area at right.



■ NUCLEAR REACTOR: Joints seal penetration of control rod drives. Meet performance of ASME Unfired Pressure Vessel Code.



■ INLET AND OUTLET REACTOR VESSEL PENETRATION; Transition sealing (stainless steel to aluminum) of thru-beam tubes at 400°F. (205°C.)

9

10

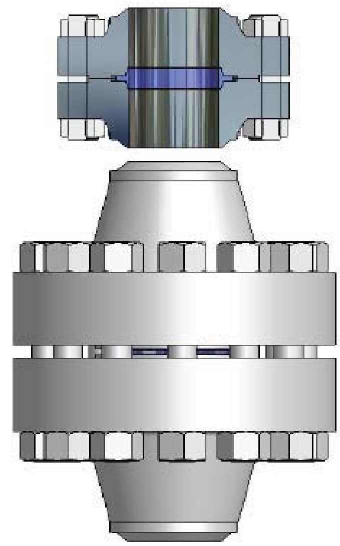
Additional information is available from:

Eaton's Aerospace Group
90 Clary Connector
Meadowbrook Road
Eastanollee, GA 30538
Ph. 706-779-7530
Fax 706-779-3752
mikewjones@eaton.com
www.eaton.com/aerospace

Appendix C—Grayloc Connections

GRAYLOC® PRODUCTS www.grayloc.com

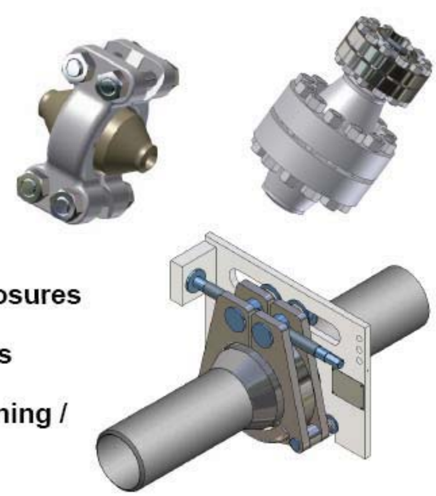
Grayloc® Compact Flanges



GRAYLOC® PRODUCTS www.grayloc.com

Grayloc® Products & Services

- Clamp Connectors
- Compact Flanges
- Metal - to - Metal Seals
- Pressure Vessels
- Specialty Connectors and Closures
- Engineering / Design Analysis
- On-Site Field Service / Machining / Conversion



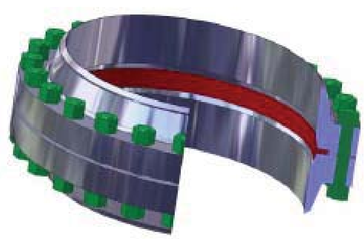
GRAYLOC® PRODUCTS www.grayloc.com

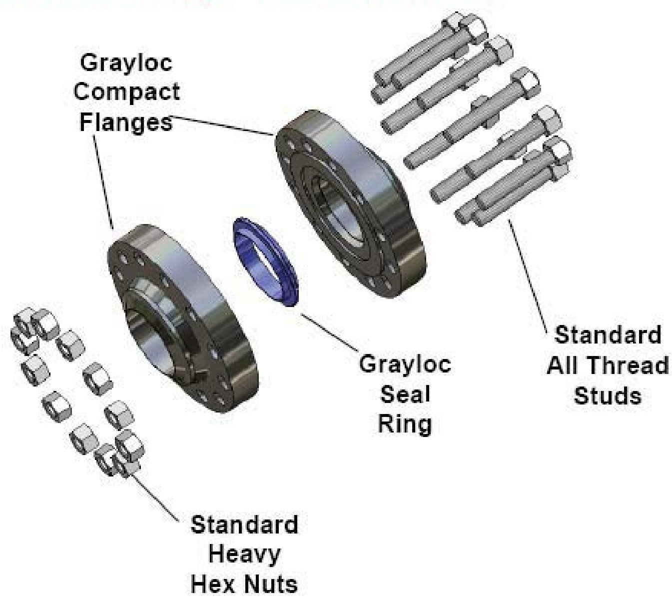
Grayloc® Compact Flange Applications

- Process Piping (ANSI 300# - 4500# / API 2M - 20M)
- Production Manifolds / Flow Lines
- Compressors / Pumps
- Vessel / Reactor Closures
- Instrumentation
- Jacketed Piping Systems
- ASME Code Pressure Vessels
- Hazardous Service (Subsea, Refinery & Nuclear)

GRAYLOC® PRODUCTS www.grayloc.com

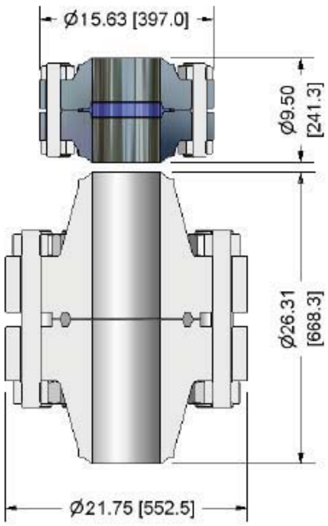
Grayloc® Compact Flange - Components





GRAYLOC® PRODUCTS www.grayloc.com

Grayloc® Compact Flange vs. ANSI Flange

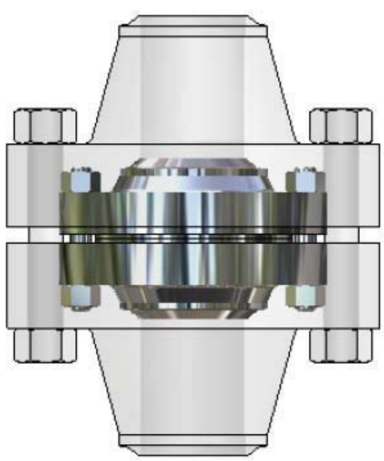


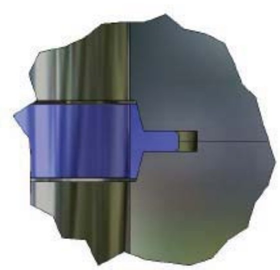
Grayloc Compact Flange – 8GCF 62
8” 2500# Service Rating
Assembly weight: 300 lbs. (136 kg)
Flange Separation Load: 205,399 lbs. (93,167 kg)

8” ANSI 2500# Flange (Group 1.1, 100° F)
Assembly Weight: 1,341 lbs (608 kg)
Flange Separation Load: 586,355 lbs. (265,966 kg)

GRAYLOC® PRODUCTS
www.grayloc.com

Grayloc® Compact Flange – Metal-to-Metal Sealing

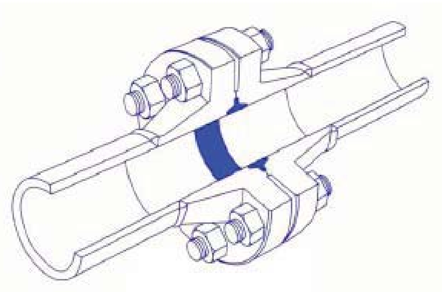




Grayloc Seal Ring:
Self-aligning
Pressure energized
Self energized
Streamline bore
Zero leak rate (10^{-6} atm cc/s Helium)

GRAYLOC® PRODUCTS
www.grayloc.com

Grayloc® Seal Ring Sizes (1/2" - 12')

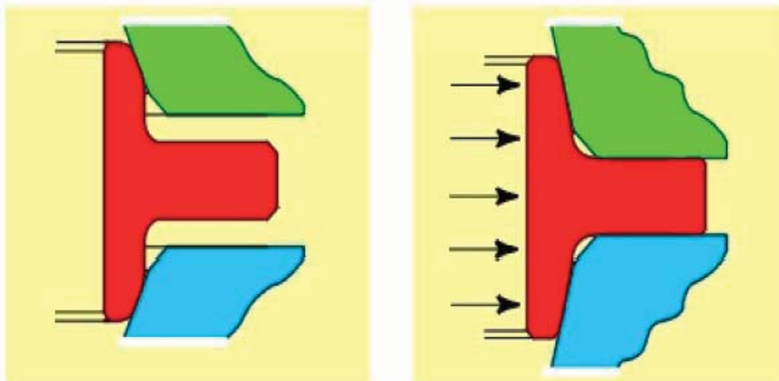


GRAYLOC® PRODUCTS www.grayloc.com

24" GCF 220 Grayloc® Compact Flanges (1500# Duplex Stainless Steel)

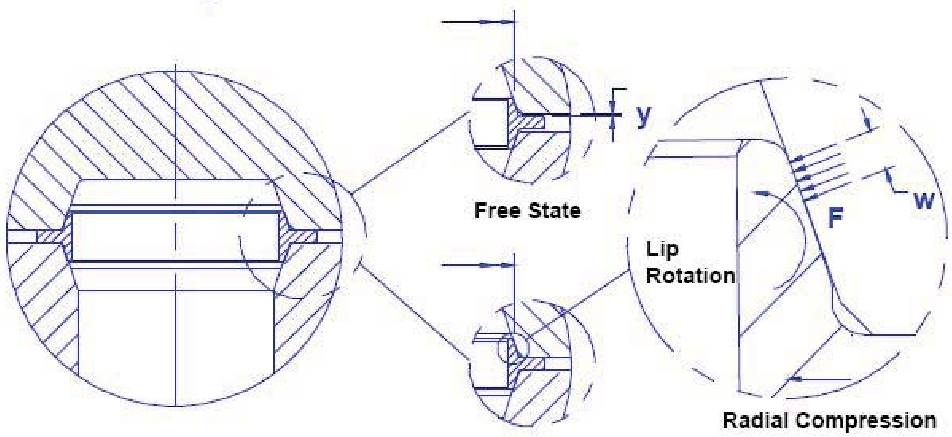
GRAYLOC® PRODUCTS www.grayloc.com

Grayloc® Self - Pressure Energized Seal



GRAYLOC® PRODUCTS www.grayloc.com

Grayloc® Metal-to-Metal Seal Contact



The seat diameter of the ring is forced smaller than the free state diameter when the Grayloc seal ring is fully seated (y = 0.0). The seal ring will seek its free state producing a sealing force (F) along the contact band (w). (F) is further increased by internal pressure. This is why the Grayloc seal ring is self-energized, pressure energized and radially energized.

GRAYLOC® PRODUCTS www.grayloc.com